Statistical Performance of TOPEX/POSEIDON Prime Mission Ground and On-Board Ephemerides and Consequences for the Extended Mission

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I. Introduction

TOPEX/POSEIDON is a joint American/French ocean topography experiment. The satellite is currently in the last year of its three year nominal mission and will then enter a three year extended mission. It was launched by an Ariane launch vehicle on August 10, 1992 to study and map ocean circulation and its interaction with the atmosphere, to improve our knowledge of climate changes and heat transport in the ocean, and to study the marine gravity field. These objectives are accomplished through accurate mapping of the ocean surface with a dual-frequency on-board radar altimeter and precision orbit determination.

To meet these science requirements, the TOPEX/POSEIDON satellite must point the altimeter antenna at the ocean local nadir with good accuracy. It must also point an articulated high gain antenna at the National Aeronautics and Space Administration (NASA) Tracking and Data Relay Satellite System (TDRSS) to allow communication and tracking for Operational Orbit Determination (0011). This requires real-time on-board knowledge of the satellite and TDRSS ephemerides. This paper will discuss only the satellite ephemeris.

The OOD is the responsibility of the Goddard Space Flight Center/Flight Dynamics Facility (GSFC/FDF). Using tracking data from TDRSS, GSFC/FDF produces satellite state vectors for transmission to the TOPEX/POSEIDON Navigation Team at JPL for use as initial conditions for propagating the Operational Orbit Ephemeris (OOE). The On-Board Computer (OBC) ephemeris commands load consists of a Fourier Power Series (FPS) representation of the OOE. Reference (1) indicates -that the overall pointing error requirement (half-cone angle) is 0.07 degrees (1-6). Portions of this overall error have been allocated to the OOE generation and the OBC ephemeris representation process. A 0.015 degree (J-o) pointing error is allocated to errors in ephemeris prediction over a seven day prediction period due to OOD and 00E generation. A 0.022 degree (1-o) pointing error is allocated to FPS representation of the OBC ephemeris over a 10 day span. Figure (1) defines the nadir pointer error and shows the relationship between it and the along track position error.

This paper shows the current statistical performance of both the OOE and the OBC ephemeris load. The consequences for the extended mission due to this performance are also discussed. The nominal mission concludes at the end of Fiscal Year 95 and more complete data will be presented in August 1995.

II. OOE Statistical Performance

The OOE is generated from GSFC/FDF supplied state vectors using the Double Precision Trajectory System program (DPTRAJ). DPTRAJ force models include: 20x20 geopotential model, luni-solar gravity, solid earth tides, atmospheric drag, solar radiation pressure, variable satellite mean area, and the anomalous force. Information on these models can be found in Reference (2).

Currently, the GSFC/FDF supplied state vectors are provided three times a week and have epochs at the start of the tracking arc, at the end of the tracking arc (seven days, ten hours past the start), and seven days after the end of the tracking arc. The first state vector is used as an initial condition for 00E propagation. Comparisons between the 00E and the remaining GSFC/FDF state vectors are made to ensure compatibility between DPTRAJ and the GSFC/FDF software.. Because the 00E includes a definitive data set, from the start to the end of the tracking arc, and a predicted portion after the end of the tracking arc, a comparison between the previous week's prediction and the current week's definitive data can be made to determine the performance of the prediction software. The difference between the predicted nadir pointing angle and the actual nadir pointing angle may be no greater than 0.015 degree (1-G) after seven days.

The performance of the OOE is investigated in three regions: the nominal sequences in which no satellite maneuvers, except for standard yaw steering, are performed, during periods when yaw maneuvers and yaw flip maneuvers are performed, and during periods when propulsive maneuvers are performed. Figure 2 shows the performance from launch through July 1994 for the nominal sequences. The pointing errors are well within the error budget.

At low β' angles, defined as the angle between the earth-sun vector and the projection of the vector onto the orbit plane, a switch from sinusoidal yaw steering of the satellite to fixed yaw steering takes place. Typical β' values for this transition are ± 15 degrees. At β' = O degrees, a 180 degree yaw flip maneuver is performed. These yaw maneuvers affect the performance of the 00E and 00D as shown in Figure 3 for a representative case. The notation "S to F" denotes the yaw steering to fixed yaw transition and "F to S" denotes the transition from fixed yaw to yaw steering. While the pointing error is still within the limit, it is three times greater than during the nominal sequences.

There have been seven propulsive orbit maintenance maneuvers to date to keep the satellite ground track within the required bounds. After such a maneuver, state vectors are supplied daily until the seven day, ten hour tracking arc is complete. The accuracy of the 00E is increased with each state vector received.

III. Performance of the OBC Ephemeris Load

The OBC ephemeris load is uploaded to the satellite weekly. A 42-coefficient FPS representation is used for each of the six Cartesian state vector components of the 00E and residuals. A grid spacing of 10 minutes was chosen for the least squares fit and the OBC recovers the ephemeris at these points. A four point Hermite interpolation formula is used by the OBC to compute position and velocity of the satellite at any requested time (Reference 3). Figure 4 shows a comparison of along track position and nadir angle pointing between the OBC ephemeris and the OOE for a representative case. The error in nadir pointing angle, due to the FPS representation, is well below the 0.022 degree limit.

Prior to the fourth orbit maintenance maneuver, three ephemerides, in addition to the standard weekly ephemeris, were generated to avoid large deviations of the post burn trajectory. These ephemeris loads were: a Predicted Post Bum (PPB) ephemeris based on the nominal maneuver design and uplinked as part of the maneuver block, a PPB ephemeris which was based on a maneuver tweak, and a no-maneuver ephemeris which is uplinked in case of no execution of the maneuver. Reference (4) suggested a strategy, later adopted, to build a single load based upon the nominal maneuver design (without the tweak). This simplified the work for the flight team and standardized plans around the maneuvers. In both cases, the performance of the PPB ephemeris depends on how closely the predicted bum matches the actual burn.

IV. Consequences for the Extended Mission

The performances of both the 00E and the OBC ephemeris load have been good. The one week 00E prediction and the ten day FPS representation errors fall well below the 1-O accuracy required, especially during the nominal sequences. This suggests that the length of the 00E and OBC ephemeris may be extended without exceeding the required error tolerance. Studies show that the 00E may be extended to 14 days and the OBC ephemeris to 20 days without reaching the error limits. Examples of the performance of the longer 00E and OBC ephemeris are shown in Figures 5 and 6 respectively. The increased spans of 14 and 20 days were chosen to double the current 00E and OBC ephemeris load lengths. The OBC ephemeris load is longer than the 00E to allow for an unexpected delay in uploading the ephemeris to the satellite. While the pointing error of the 00E has increased by a factor of 3, it is still an order of magnitude less than the allowed maximum. The pointing error of the 20 day OBC ephemeris load is comparable to that of the 10 day load,

Based on this study, a proposal to decrease the frequency of the OBC ephemeris load uplink from one week to two weeks will be made to the TOPEX/POSEIDON project. This will reduce the level of support required from mission operations while still maintaining acceptable satellite pointing accuracy. For full implementation, changes to the flight software will need to be made. These changes include adjusting the satellite clock length from 12 days to 20 days and adjusting the FPS coefficient scale factors.

References

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2. Salama, A., M. Nemesure, J. Quinn, D. Bolvin, and R. Leavitt, "Compatibility of TOPEX/POSEIDON Trajectory Propagation with JPL and GSFC/FDF Operational Software," Flight Mechanics/Estimation Theory Symposium, 17-19 May 1994, GSFC, Greenbelt, Maryland.

3. Salama, A., "On-Board Ephemeris Representation for TOPEX/POSEIDON," AIAA/AAS Astrodynamics Conference, Portland, Oregon, AIAA-90-2957, August 1990.

4. Salama, A. and P. Sanatar, "Proposed Predicated Post Burn (PPB) Ephemeris Strategy for OMMs," JPL IOM 312/93.6-679, October 1, 1993 (Internal Document).

Figure 1. Nadir Pointing Geometry

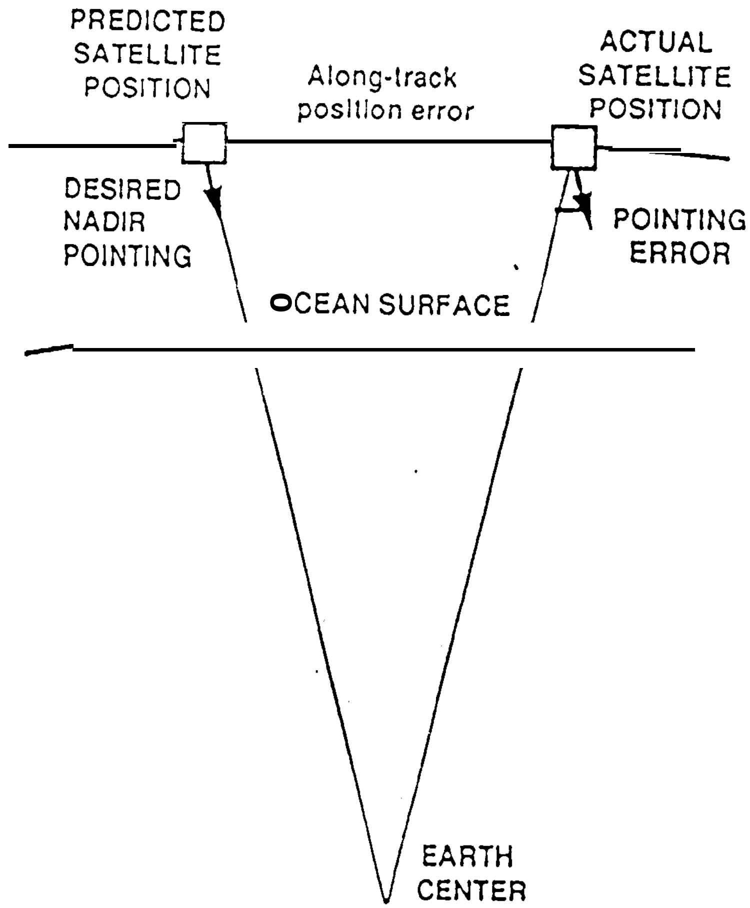

Figure 2. ∞E Pointing Accuracy

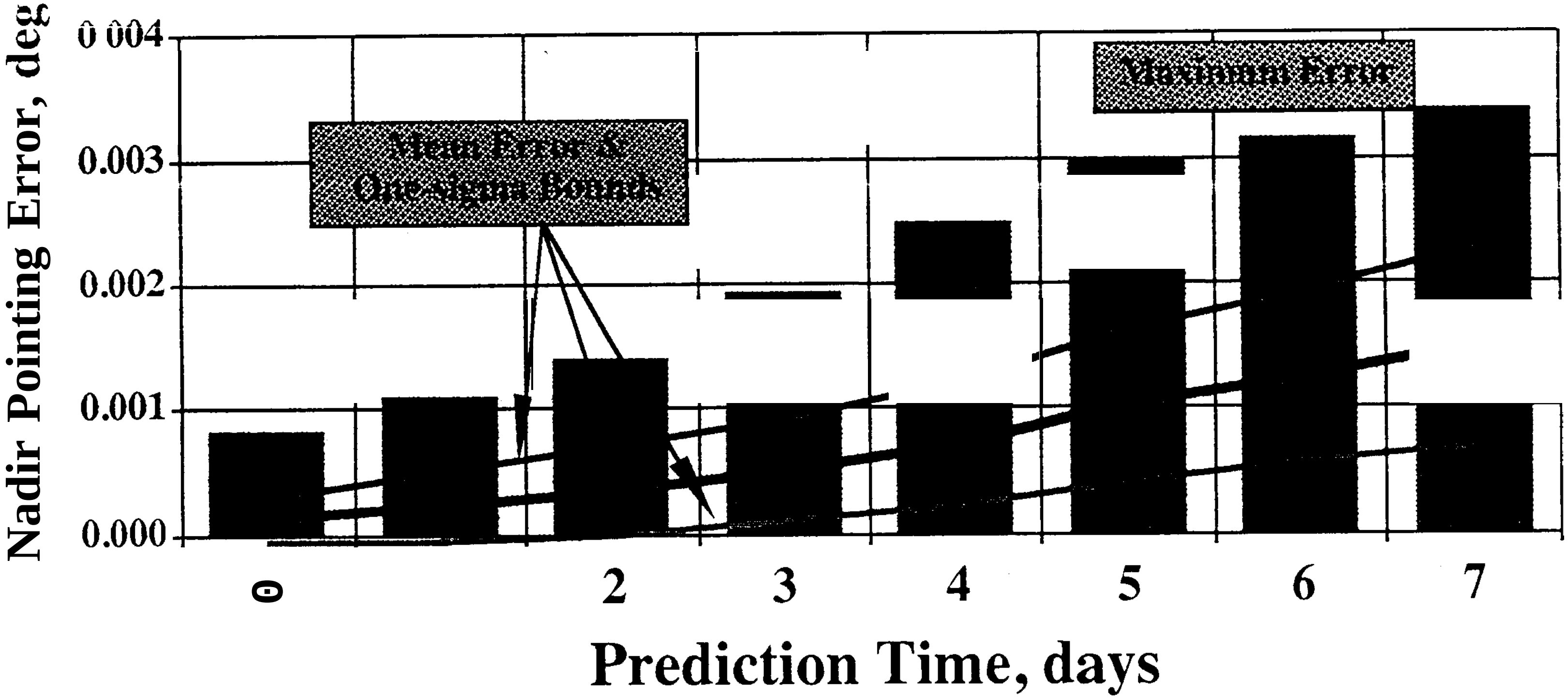

Figure 3. OOE Pointing Accuracy (Last Yaw Flip Before OMM3)

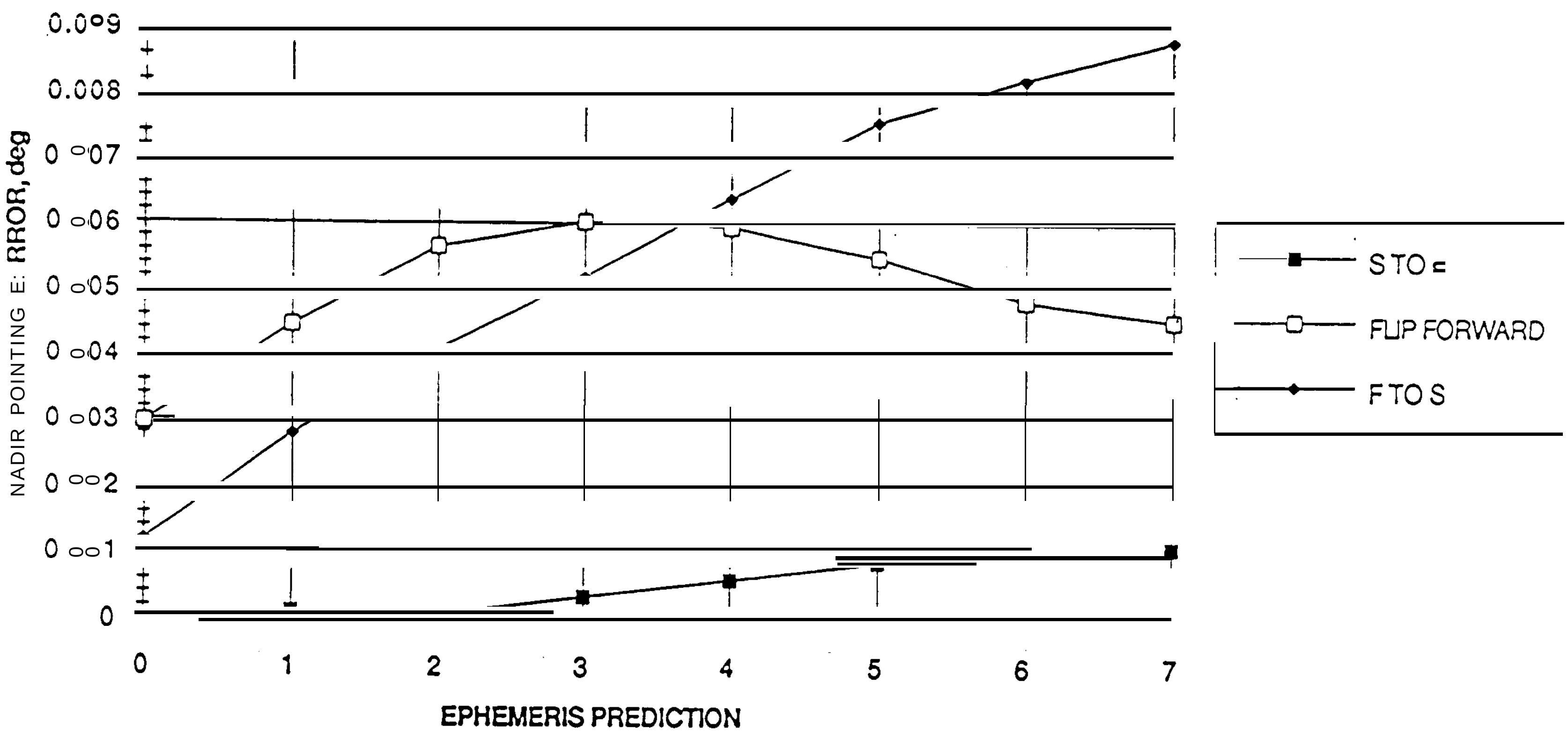

Figure 4. OBC Ephemeris Performance

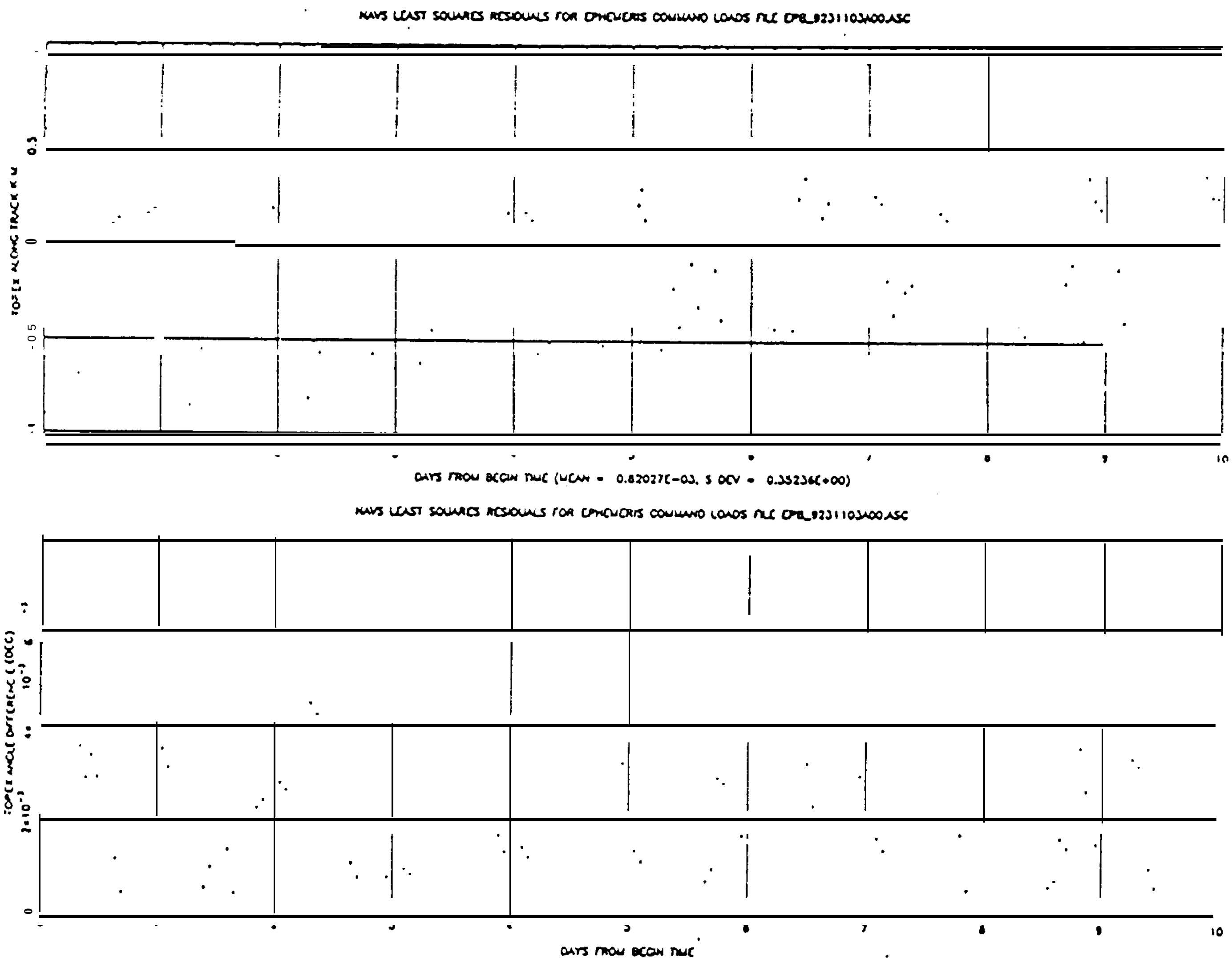

Figure 5. OOE Performance For Two Week Period

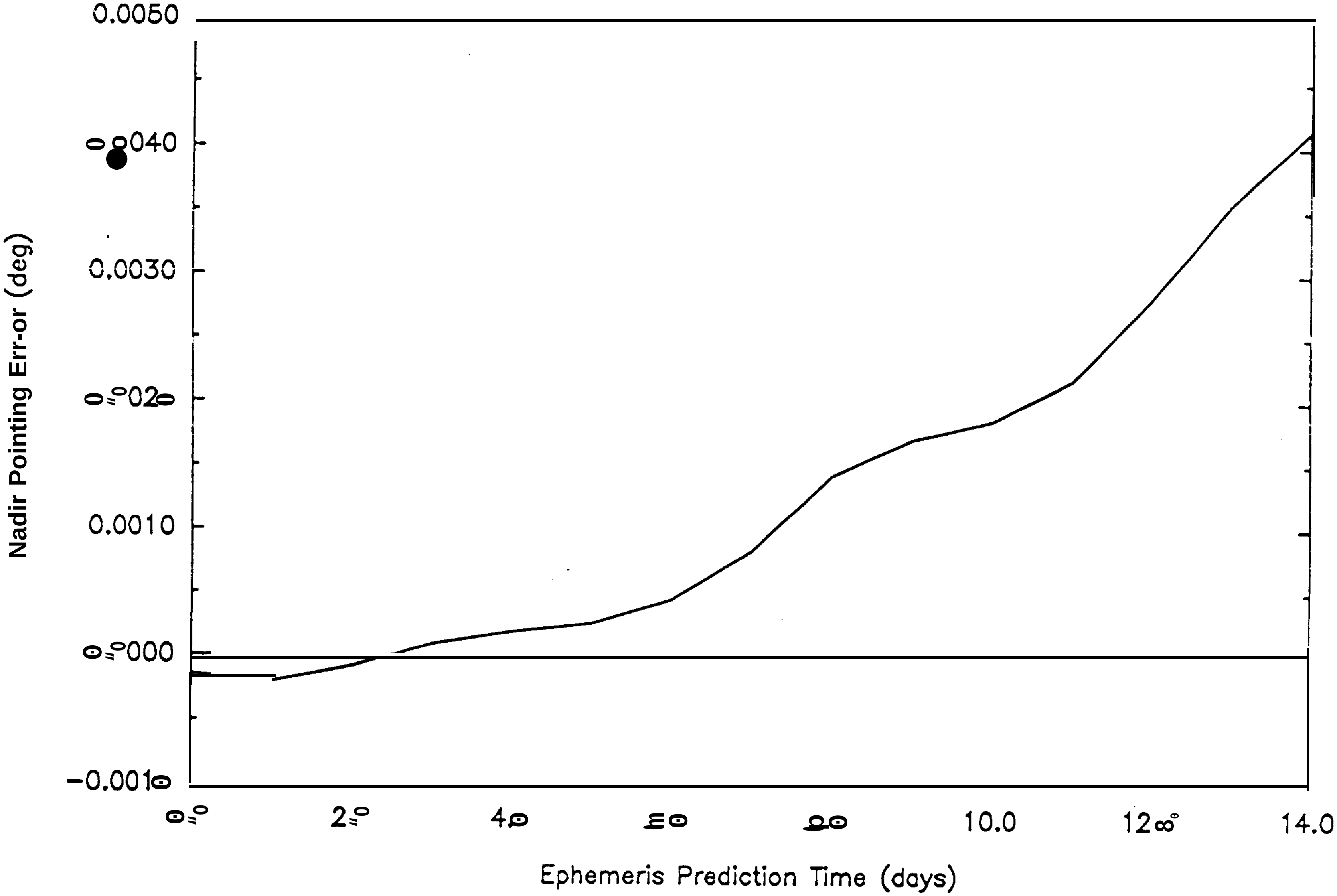

Figure 6. 20 Day OBC Ephemeris Performance